

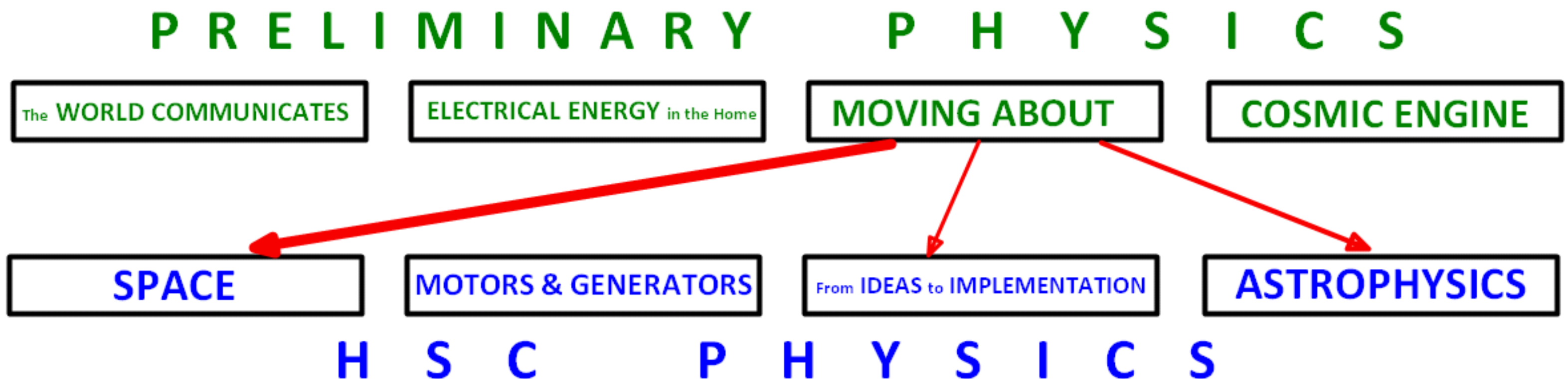
MODULE 3: MOVING ABOUT

ENERGY, WORK AND CONSERVATION OF ENERGY

PERIOD 6

6 AUGUST 2009

WEEK 2 / TERM 3 - THURSDAY



MOVING ABOUT - 3

Moving vehicles have kinetic energy, and energy transformations are an important aspect in understanding motion.

Students learn to:

- identify that a moving object possesses kinetic energy and that work done on that object can increase that energy
- describe the energy transformations that occur in collisions
- define the Law of Conservation of Energy

Students:

- solve problems and analyse information to determine the kinetic energy of a vehicle and the work done using the formulae: $E_k = \frac{1}{2} mv^2$ and $W = Fs$
- analyse information to trace the energy transfers and transformation in collisions leading to irreversible distortions

1. NEWTON'S FIRST LAW > LAW OF INERTIA

NEWTON'S FIRST LAW OF MOTION states that a body will either remain at rest or continue with constant speed in a straight line (i.e. constant velocity) unless it is acted on by an unbalanced force.

2. NEWTON'S SECOND LAW > $F = ma$

NEWTON'S SECOND LAW OF MOTION states that the acceleration of a body, ***a***, is directly proportional to the net force acting on it, $\Sigma \mathbf{F}$, and inversely proportional to its mass, *m*:

$$\Sigma \mathbf{F} = m\mathbf{a}$$

3. NEWTON'S THIRD LAW > ACTION-REACTION

NEWTON'S THIRD LAW OF MOTION states that for every action force (object A on B), there is an equal and opposite reaction force (object B on A):

$$\mathbf{F}(\text{A on B}) = -\mathbf{F}(\text{B on A})$$

ENERGY

Most dictionaries and some physics textbooks define energy as the capacity to do **work**. Work is done when an object moves in the direction of a force applied to it.

- ✓ All matter possesses energy.
- ✓ Energy is a scalar quantity — it does not have a direction.
- ✓ Energy takes many different forms. It can therefore be classified. Light energy, sound energy, thermal energy, kinetic energy, gravitational potential energy, chemical energy and nuclear energy are some of the different forms of energy.
- ✓ Energy can be stored, transferred to other matter or transformed from one form into another. For example, when you hit a cricket ball with a bat, energy is transferred from the bat to the ball. When you dive into a swimming pool, gravitational potential (stored) energy is transformed into kinetic energy.
- ✓ Some energy transfers and transformations can be seen, heard, felt, smelt or even tasted.
- ✓ It is possible to measure the quantity of energy transferred or transformed.
- ✓ Energy cannot be created or destroyed. This statement is known as the Law of Conservation of Energy. The quantity of energy in the universe is a constant. However, nobody knows how much energy there is in the universe.

Table 7.1 Comparison of various energy transformations.

Energy use	Amount of energy
Household in 1 day	150 MJ
Fan heater in 1 hour	8.6 MJ
Adult food intake in 1 day	12 MJ
Making 1 Big Mac	2.1 MJ
Climbing a flight of stairs	5 kJ
Lifting 10 kg to a height of 2 m	200 J

Energy can be defined as the capacity to do work. It is a scalar quantity.

Work is done when an object moves in the direction of a force applied to it. The amount of work done is the product of the magnitude of the force and the displacement of the object in the direction of the force. Work is a scalar quantity.

It is important to distinguish between the words transferred and transformed when describing energy changes.

- *The word transfer, when used as a verb, is defined in The Macquarie Dictionary as meaning, among other things: ‘... to convey or remove from one place, person, etc. to another’.*
Energy can be transferred from one object to another.
- *The word transform is defined in The Macquarie Dictionary as meaning, among other things: ‘... to change in form; change to something of a different form; metamorphose ...’.*
Energy can be transformed from one form into another form.

$$\frac{1}{2}mv^2$$

$$m \rightarrow \text{kg}$$

$$v \rightarrow \text{m/s}$$

$$E_k \rightarrow \text{J (Joules)}$$

$$1 \text{ J} = \frac{\text{kg m}^2}{\text{s}^2}$$

Worked example 7.2A.

Calculate the kinetic energy of an athlete of mass 60 kg running at a speed of 8.0 m s⁻¹.

Solution

$$m = 60 \text{ kg}, v = 8.0 \text{ m s}^{-1}$$

$$\text{Using } E_k = \frac{1}{2}mv^2:$$

$$E_k = \frac{1}{2} \times 60 \times 8.0^2 \\ \approx 1900 \text{ J.}$$

Table 7.2 Kinetic energy of moving objects.

Object	Mass (kg)	Average speed (m s ⁻¹)	E_k (J)
Earth in orbit	6×10^{24}	3×10^4	2.7×10^{33}
Orbiting satellite	100	8×10^3	3×10^9
Large car	1400	28	5.5×10^5
Netball player	60	8	1900
Footballer	90	8	2900
Electron in a TV tube	9×10^{-31}	7×10^7	2.2×10^{-15}

Calculate the kinetic energy of a:

- a** 1.0 kg mechanics trolley with a velocity of 2.5 m s^{-1}

$$E_k = \frac{1}{2} 1 \times 2.5^2 = 3.125 \text{ J}$$

- b** 5.0 g bullet travelling with a velocity of 400 m s^{-1}

$$E_k = \frac{1}{2} 0.005 \times 400^2 = 400 \text{ J}$$

- c** 1200 kg car travelling at 75 km h^{-1} .

$$E_k = \frac{1}{2} 1200 \times \cancel{15} \left(\frac{75}{3.6} \right)^2 = \cancel{102500} 260000 \text{ J}$$

11.2

Kinetic energy calculations

Compare the kinetic energy of a 100 m Olympic track athlete with that of a family car travelling through the suburbs.

athlete

$$m = 80 \text{ kg}$$

$$v = 10 \text{ m/s}$$

$$E_k = \frac{1}{2} 80 \times 10^2$$
$$= 4000 \text{ J}$$

car

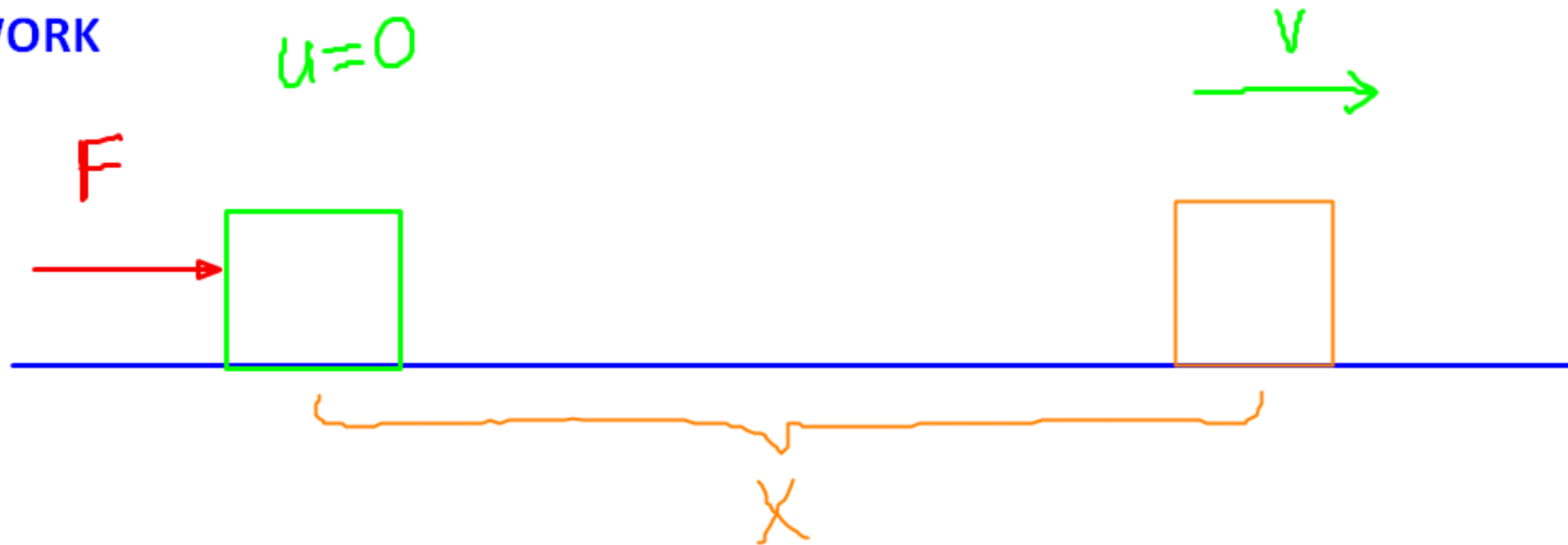
$$m = 1000 \text{ kg}$$

$$v = 50 \text{ km/h}$$

$$E_k = \frac{1}{2} 1000 \times \left(\frac{50}{3.6} \right)^2$$
$$= 96500 \text{ J}$$

$$E_{k \text{ car}} = 24 \times E_{k \text{ ath.}}$$

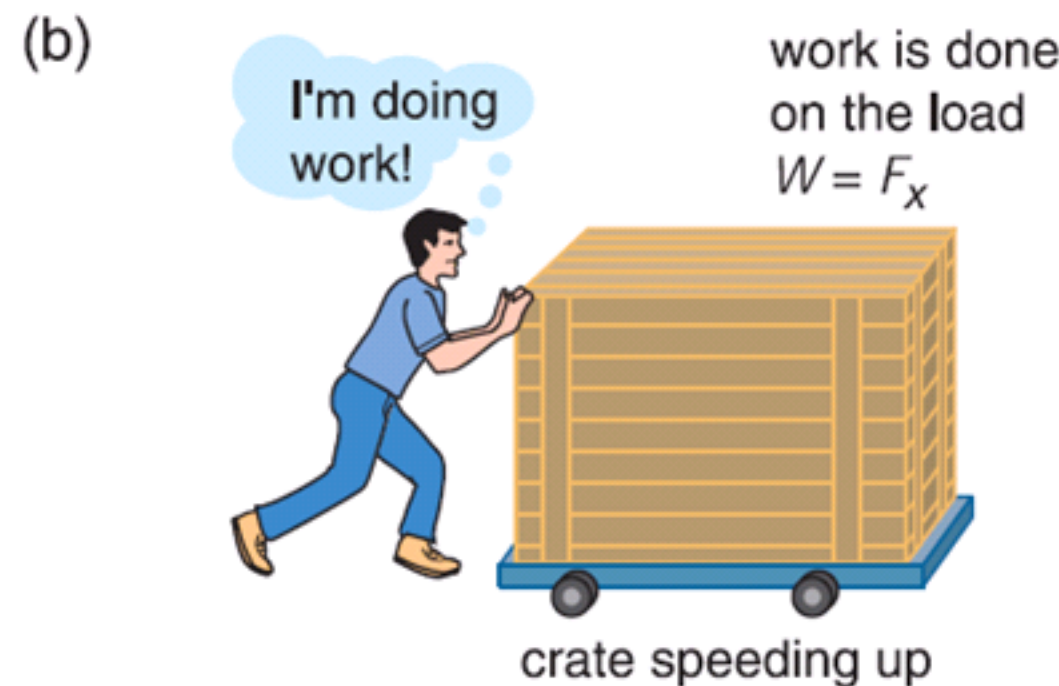
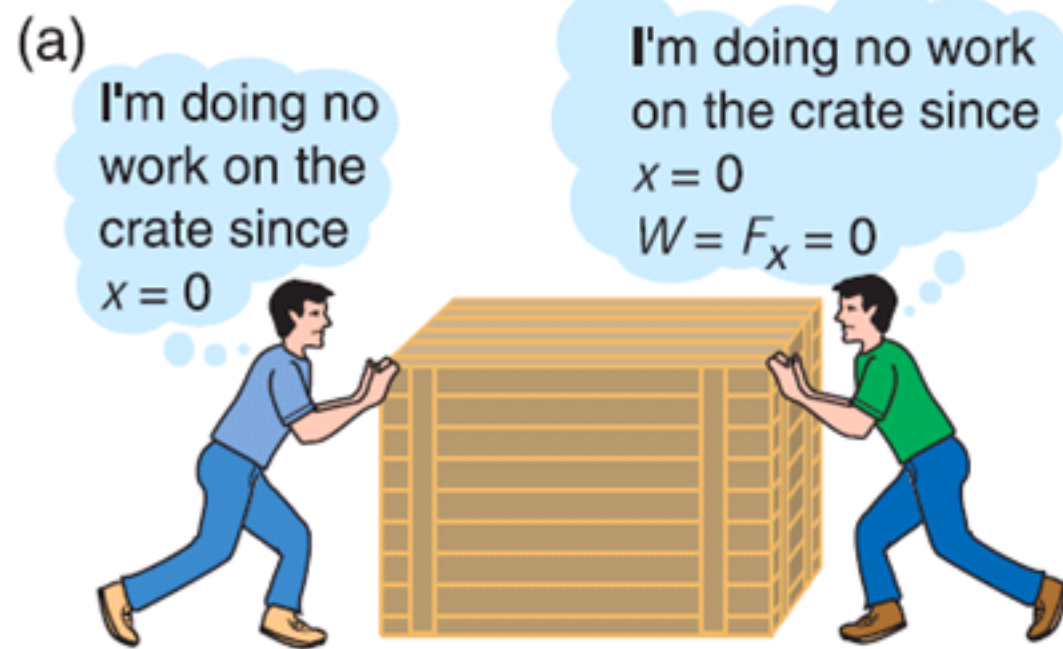
WORK



Work = Force \times Distance

$$W = F \cdot s$$

→ Increases the mechanical en. of the object



$$W = \Delta E$$

Figure 7.2 (a) No work is done on the crate since its energy is not altered.
(b) Since the energy of the crate is changing, work is being done on the crate.

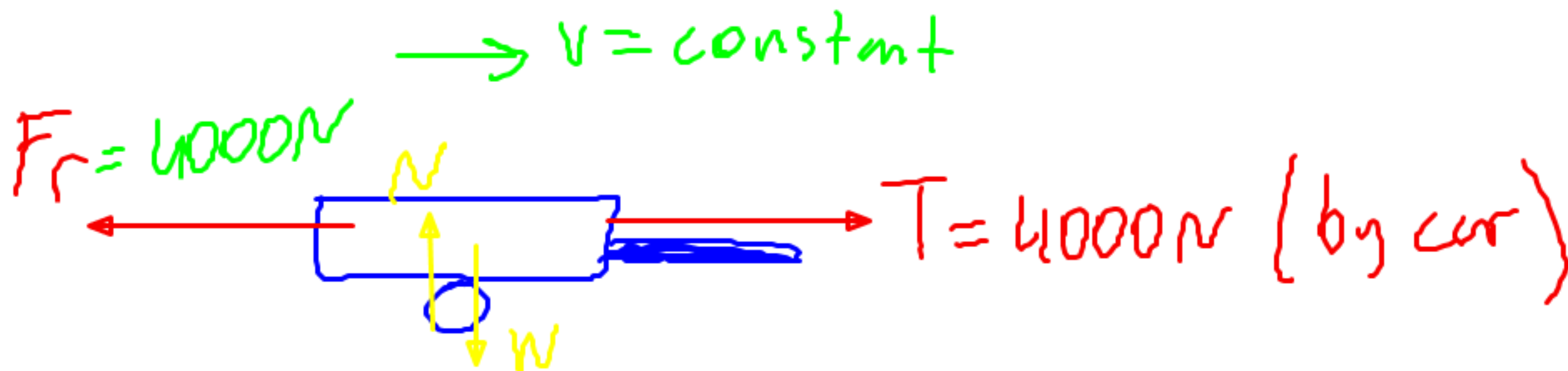
11.1

Doing work to change kinetic energy

A trailer is being pulled along a straight, rough, horizontal road by a car. The trailer and the car travel at a constant speed of 50 km h^{-1} . The forward force applied to the trailer by the car is 4000 N . Frictional forces oppose this force.

- (a) In moving a horizontal distance of 500 metres , how much work is done on the trailer by:
- the car?
 - the net force?
 - the force of gravity?
- (b) If the force applied to the trailer by the car is increased to 5000 N and nothing else changes, how much kinetic energy is gained by the trailer over the distance of 500 metres ?

$$\begin{aligned} \text{b) } F_{\text{net}} &= 1000 \text{ N} \\ W &= 1000 \times 500 \\ &= 500000 \text{ J} = 0.5 \text{ MJ} \end{aligned}$$



- a) i) $W = F \cdot s = 4000 \times 500 = 2000000 \text{ J} = 2 \text{ MJ}$
- ii) $F_{\text{net}} = 0 \Rightarrow W = 0$
- iii) Since weight is not contributing to the motion
 $s = 0 \quad W = 0$

WHAT ABOUT FRICTION?

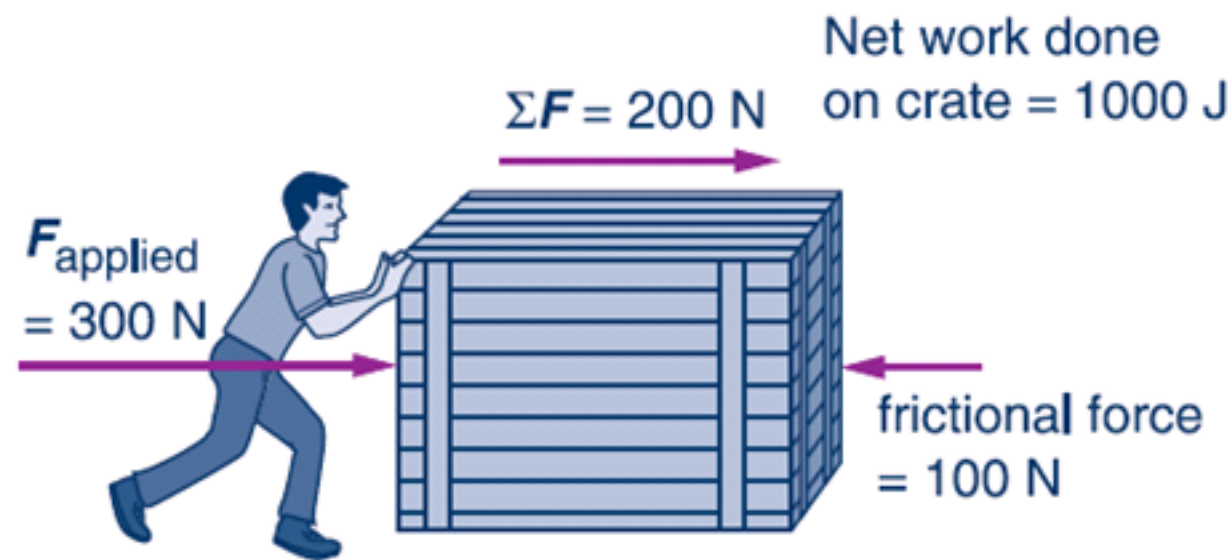


Figure 7.5 The object slides across a displacement of 5 m. Due to friction the net work done on the object is less than the work done by the person on the object.

$$W_{\text{on the crate}} = 200 \times 5 = 1000 \text{ J}$$

$$W_{\text{by worker}} = 300 \times 5 = 1500 \text{ J}$$

$$W_{\text{by friction}} = 100 \times 5 = 500 \text{ J}$$

$$1500_{\text{worker}} = 1000_{\text{crate}} + 500_{\text{friction}}$$

WHAT IF VELOCITY IS CONSTANT?

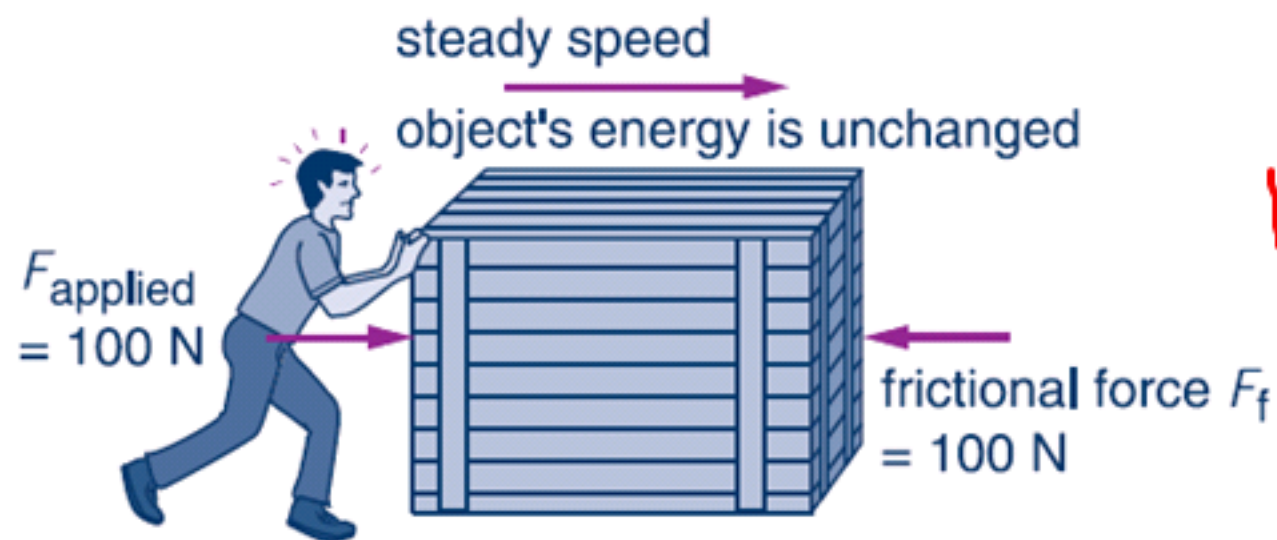


Figure 7.6 Due to friction the *net* work done on the object is zero since the object has no increase in kinetic energy.

$$W_{\text{by worker}} = 100 \times 5 = 500 \text{ J}$$

$$W_{\text{against fr}} = 100 \times 5 = 500 \text{ J}$$

$$W_{\text{on crate}} = 0 \quad (F_{\text{net}} = 0)$$

$$W = \Delta E$$

WHAT IF THE FORCE APPLIED IS MAKING AN ANGLE WITH THE DIRECTION OF THE MOTION?

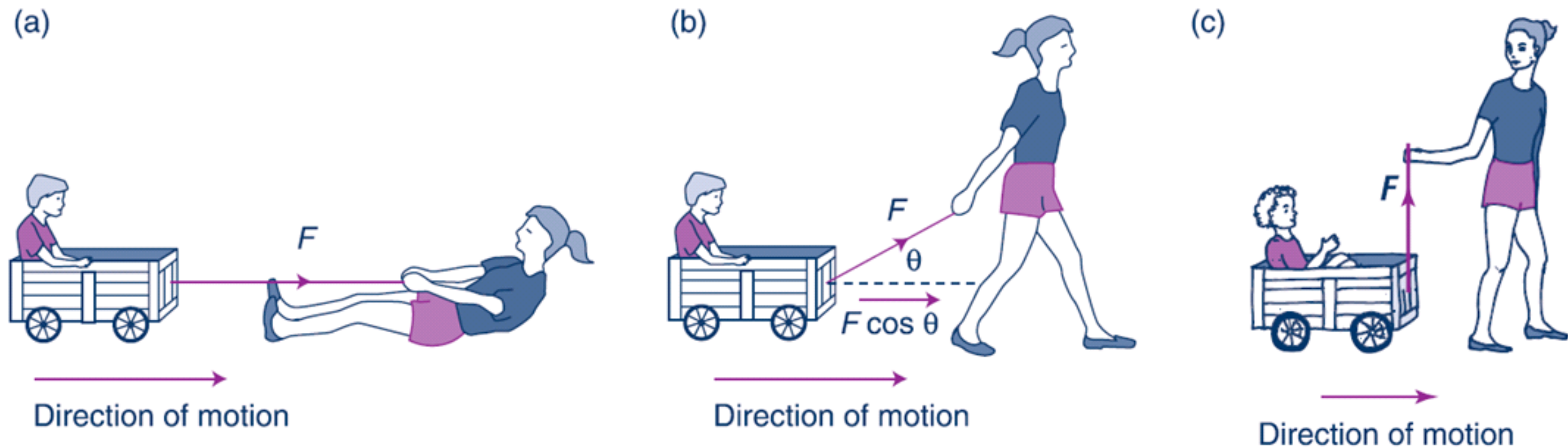


Figure 7.4 (a) If a force is applied in the direction of motion of the cart, then the force is at its most effective in moving the cart. (b) When the force is applied at an angle θ to the direction of motion of the cart, the force is less effective. The component of the force in the direction of the displacement, $F \cos \theta$, is used to calculate the work. (c) When the angle at which the force is acting is increased to a right angle ($\theta = 90^\circ$), then the component of the force in the direction of the intended displacement is zero and it does no work on the cart—provided of course that it doesn't lift the cart, in which case work would also be done against gravity.

A rope that is at 35° to the horizontal is used to pull a 10.0 kg crate across a rough floor. The crate is initially at rest and is dragged for a distance of 4.00 m. The tension in the rope is 60.0 N and the frictional force opposing the motion is 10.0 N.

- a** Draw a diagram illustrating the direction of all relevant forces.
- b** Calculate the work done on the crate by the tension in the rope.
- c** Find the total work done on the crate.
- d** Determine the energy lost from the system as heat and sound due to the frictional force.



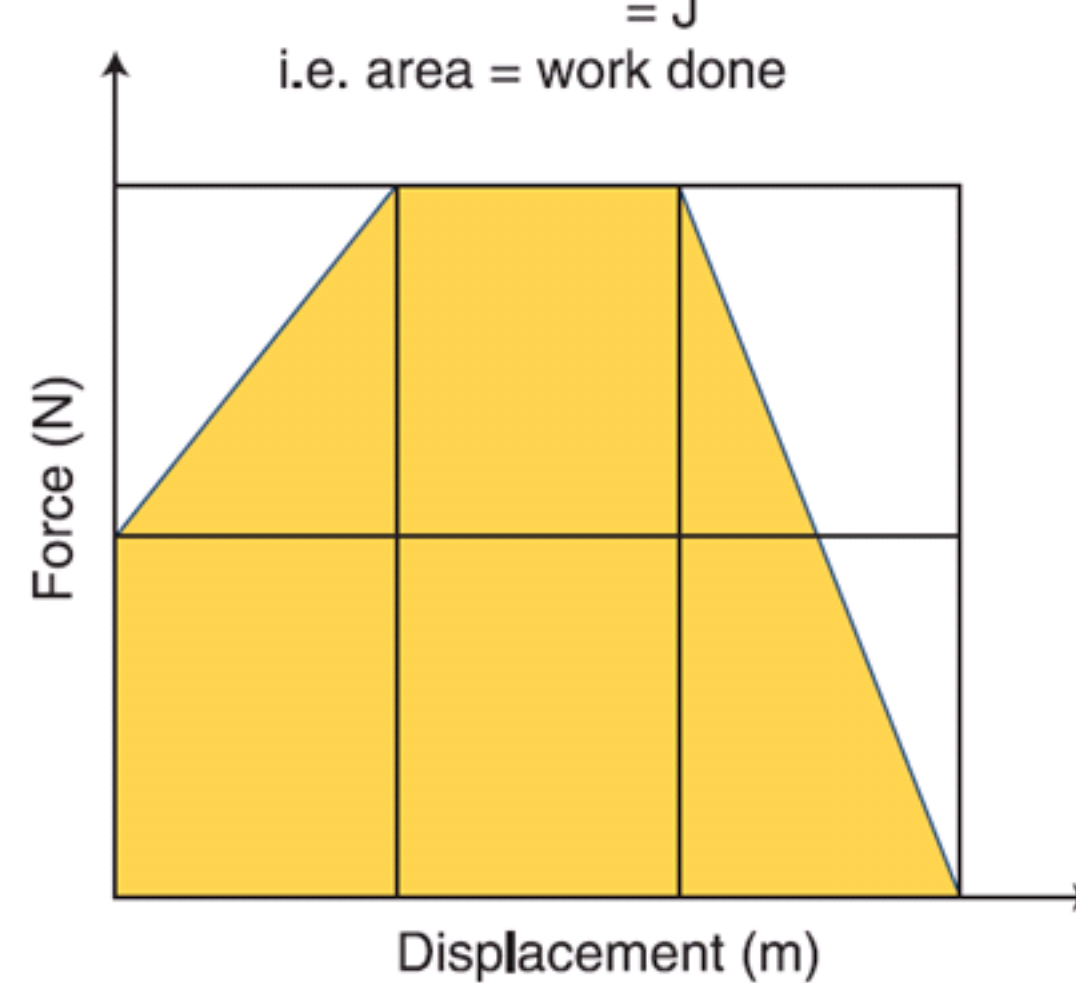
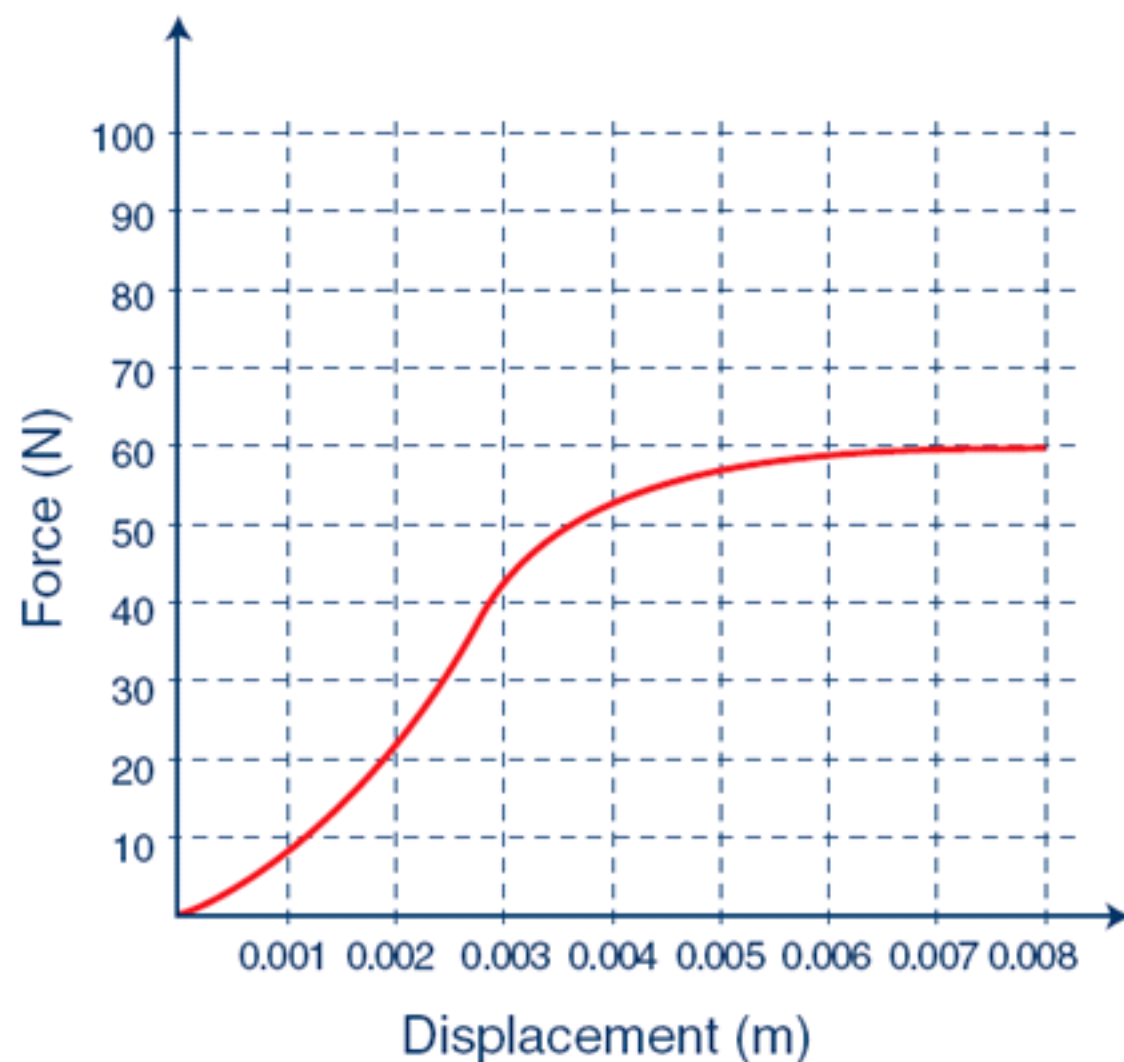


Figure 7.8 The area under a force–displacement graph is equivalent to the work done by a force acting in the direction of the displacement. Where the net applied force is changing, then the area can be found by counting squares or dividing the area into segments. The area of each segment then equals the work done by a constant force during that small displacement and the total area will represent the total work.



Worked example 7.1C

The force–displacement graph on the left represents the work done on the sole of a sports shoe as it compresses against the surface of a rigid track. The displacement shown represents the amount of compression the sole undergoes. Find the work done on the shoe by the compressive forces.

Solution

This is a simple case of working out the area represented by each square and then counting the total number of squares to find the total work done. Be careful to consider the scale of each axis in your working.

$$\text{Area of one square} = 10 \text{ N} \times 0.001 \text{ m} = 0.01 \text{ J}$$

Total number of squares (part squares can be added to give whole squares) = 33

$$\text{Work} = 33 \times 0.01 = 0.33 \text{ J}$$

WHAT HAPPENS TO KE WHEN TWO CARS COLLIDE?!

When a vehicle collides with a stationary object or another vehicle, some of its kinetic energy is transferred to the object or vehicle. Some of the kinetic energy is still possessed by the vehicle if it does not stop. The remaining kinetic energy is transformed into other forms of energy. These forms include:

- ✓ **Potential energy of deformation.** Potential energy of deformation is the energy stored in an object as a result of changing its shape. Sometimes that potential energy of deformation can be easily transformed back into other forms when the object returns to its original shape. When the panels of a car are deformed, it is much more difficult to return them to their original shape.
- ✓ **Sound energy.** Sound energy is transmitted through the air as a result of vibrating particles. When a vehicle collides with an object or another vehicle, some of its kinetic energy is transferred to the surrounding air, causing it to vibrate rapidly.
- ✓ **Thermal energy.** Thermal energy is energy that a substance possesses as a result of the random motion of the particles within the substance. The vehicle's panels, tyres and other parts get very hot during the collision as kinetic energy is transferred to the particles within them. The other object or vehicle, and even the immediate surrounding road and air, are also heated.

The Law of Conservation of Energy applies to vehicle collisions, as it does to all interactions. The car's kinetic energy is never really 'lost' or destroyed. It is all transferred to other objects or transformed into other forms.

Worked example 7.2B.

Blood is pumped by the heart into the aorta at an average speed of 0.15 m s^{-1} . If 100 g of blood is pumped by each beat of an adult human's heart find:

- a** the amount of work done by the heart during each contraction
- b** the energy used by the heart each day in pumping blood through the aorta (use an adult's average resting rate of 70 beats per minute). Assume that there are no other energy losses.

Solution

- a** The work done by the heart is equal to the kinetic energy the blood gains as it is pumped into the aorta.

$$m = 0.10 \text{ kg}, v = 0.15 \text{ m s}^{-1}, u = 0 \text{ m s}^{-1}$$

$$\text{Using } W = \Delta E_k = \frac{1}{2}m(v^2 - u^2)$$

$$W = \frac{1}{2} \times 0.10 \times (0.15^2 - 0^2)$$

$$W = 1.125 \times 10^{-3} \text{ J} = 1.1 \text{ mJ}$$

- b** If there are 70 beats each minute then the amount of energy transferred:

$$E_k \text{ per minute} = 1.125 \times 10^{-3} \times 70 = 0.07875 \text{ J per minute}$$

$$E_k \text{ per day} = 0.07875 \times 60 \text{ min per hour} \times 24\text{-hour day}$$

$$E_k = 113.4 \text{ J per day} \approx 110 \text{ J per day}$$

HOMEWORK

- ★ Homework is an integral part of your "Learning Curve", take it seriously!
- ★ If you cannot do all, at least do a few from each piece
- ★ Target minimum 1 hour of Physics everyday
- ★ Homework is due next period, unless otherwise stated

Apart from reading the relevant pages from the textbook your homework is:

1. Read all pages and study worked examples of Chapter 11 page 226 - 230
2. Chapter 11 questions 1 to 8
3. Worked Examples in this booklet

STILL...

1. Yellow Worksheet all questions
2. Chapter 10 All Questions
3. log on to

"<http://www.academicearth.org/courses/physics-i-classical-mechanics>"
and watch Lectures 5 and 6

A MASSIVE HOMEWORK WILL BE GIVEN FOR WEEKEND - YOU BETTER FINISH THESE TONIGHT!!!

HOMEWORK

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1. Read all pages and study worked examples of Chapter 10.
2. Yellow Worksheet all questions
3. Chapter 10 all questions
4. Worked Examples in this booklet
5. log on to
"<http://www.academicearth.org/courses/physics-i-classical-mechanics>"
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